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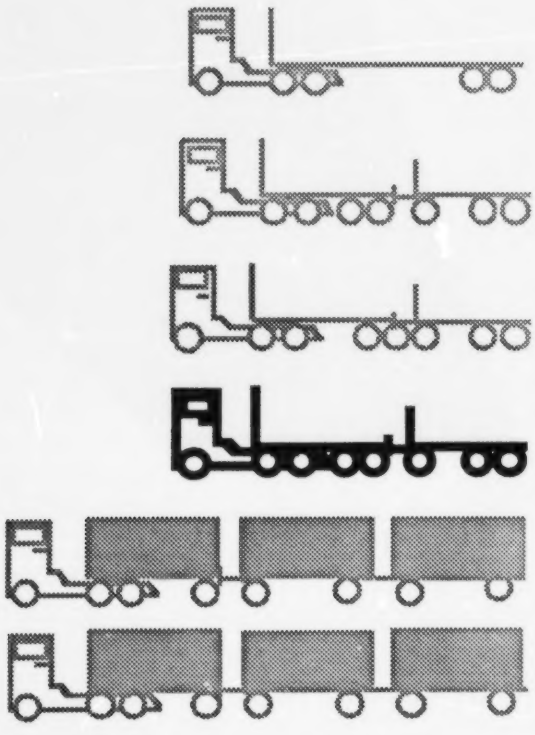
Demonstration of Baseline Vehicle Performance: C-Train Double



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Demonstration of Baseline Vehicle Performance: C-Train Double

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Prepared for:
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Abstract:

A C-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

A C-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a base-line vehicle and the representative test vehicle for similar configurations.

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TABLE OF CONTENTS

	PAGE
1/ INTRODUCTION	1
2/ TEST VEHICLE DESCRIPTION	2
3/ TEST PROGRAM	4
3.1/ Test Procedures	4
3.2/ Instrumentation	5
3.3/ Data Capture and Data Processing	5
4/ RESULTS	7
4.1/ Offtracking	7
4.2/ Right-Hand Turn	7
4.3/ Channelized Right Turn	8
4.4/ Air Brake System	8
4.5/ Straight-Line Braking	9
4.6/ Evasive Manoeuvre	10
4.7/ Sinusoidal Steer	10
4.8/ Lane Change	11
4.9/ Normal Straight-Line Driving	12
4.10/ Steady Circular Turn	12
5/ DISCUSSION	14
6/ CONCLUSIONS	15
7/ REFERENCES	16

LIST OF FIGURES

	PAGE
1/ C-Train Double, View of Vehicle	18
2/ C-Train Double, Vehicle Dimensions.	18
3/ C-Train Double, Clockwise Offtracking	19
4/ C-Train Double, Counter-Clockwise Final Offtracking	19
5/ C-Train Double, Right-Hand Turn Swept Path.	20
6/ C-Train Double, Right-Hand Turn	21
7/ C-Train Double, Channelized Right Turn.	21
8/ C-Train Double, Channelized Right-Turn Clearance from Inner Curb	22
9/ C-Train Double Trailers and Dolly, Air Brake System Schematic	23
10/ C-Train Double, Air Brake Application and Release	24
11/ C-Train Double, Vehicle Response to Straight-Line Braking	25
12/ C-Train Double, Straight-Line Breaking Responses vs Treadle Valve Pressure	26
13/ C-Train Double, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed	27
14/ C-Train Double, Vehicle Response in Evasive Manoeuvre	28
15/ C-Train Double, Rearward Amplification of Lateral Acceleration	29
16/ C-Train Double, Sinusoidal Steer, Vehicle Responses at 94 km/h.	30
17/ C-Train Double, Lane Change, Vehicle Responses vs Speed.	31
18/ C-Train Double, Lane Change, Vehicle Responses at 95 km/h.	32
19/ C-Train Double, Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration	33
20/ C-Train Double, Steady Circular Turn, Vehicle Responses at 61 km/h.	34
21/ C-Train Double on Tilt Table.	35

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a C-train double trailer combination baseline vehicle. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and two tandem-axle flatbed semitrailers with a single-axle B-type converter dolly. The combination is typical of equipment used in all regions of Canada, except the Atlantic provinces, though the C-train configuration is much less common than the A-train. The same combination was also tested concurrently as an A-train, using an A-type converter dolly [3].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailers or dolly except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailers used were both manufactured by Fruehauf in Winnipeg and were model PB-F2-26-102-SF with serial numbers DXT2796-08 and DXT2796-06. Each trailer had a nominal length of 7.93 m (26 ft) and a nominal width of 2.59 m (102 in). Each had two axles spaced 1.24 m (49 in) apart and suspended from a Reyco 21B four- spring leaf suspension system with torque rods and equalizer arms. The spring centre spacing for each trailer was 0.96 m (38 in), and the track width was 1.45 m (57 in). The dolly was made from the ASTL SSD frame, used in previous tests [12], and a Sauer model RLZ 10041 self-steering axle rated at 10 000 kg and placarded for a speed of 80 km/h. Suspension was a Reyco two-spring leaf system with a torque rod. The B-dolly had a spring centre width of 0.76 m (30 in), and the track width was 2.44 m (96 in). The fifth-wheel-to-hitch distance was 1.98 m (6.5 ft). The combination had an overall length of 20.97 m (68.8 ft).

The trailers and dolly were fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 600 km (370 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 24 196 kg (53 230 lb). Concrete blocks were used to obtain a loaded weight of

48 668 kg (107 070 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 832	10 630	5 127	11 280
2	3 700	8 140	5 445	11 980
3	3 218	7 080	5 464	12 020
4	2 073	4 560	5 664	12 460
5	2 355	5 180	6 536	14 380
6	3 518	7 740	7 727	17 000
7	2 445	5 380	6 814	14 990
8	2 055	4 520	5 891	12 960
Total	24 196	53 230	48 668	107 070

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was not closely attained. Both trailers were loaded in the same fashion. The legal gross weight of the vehicle tested varies between 52 800 and 61 600 kg (116 160 and 135 520 lb), depending on the province.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.37 m (14.7 in) below the top of the floor. The centre of gravity height was estimated as 0.20 m (8 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments were installed on the trailers, and safety cable attachments were installed on the dolly.
3/ Outriggers were installed on the trailers.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer beds to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailers.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 600 km (370 mi).
14/ Articulation angle between the tractor and lead trailer was calibrated.
15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailers and dollies for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the two trailers were mounted in boxes placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	23.194°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 steer angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
23	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi
24	Brake pressure, axle 8 right	Celesco PLC-200G	106.79 psi
25	Spare		
26	Spare		
27	Trailer 2 articulation angle	Spectrol 8409 potentiometer	22.8°
28	Trailer 2 lateral acceleration	Columbia SA-107 accelerometer	0.980 g
29	Trailer 2 roll angle	Humphrey VM02-0128-1 vertical gyro	8.91°
30	Trailer 2 outrigger touchdown	Strain gauge bridge	1.0 V

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [13]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 1.35 m (4.34 ft), shown in Figure 4, became 1.31 m (4.29 ft).

Table 3/ Offtracking

Axle No.	Track Width	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.53	27.68	0.15	27.60	27.56	-0.14
2	2.37	27.24	27.30	0.06	27.27	27.21	-0.22
3	2.37	27.23	27.26	0.03	27.25	27.21	-0.15
4	2.37	26.63	26.65	0.01	26.64	26.64	0.00
5	2.37	26.60	26.61	0.01	26.61	26.64	+0.11
6	2.37	26.67	26.67	0.00	26.67	26.86	+0.71
7	2.37	26.20	26.23	0.03	26.22	26.29	+0.27
8	2.37	26.17	26.20	0.03	26.19	26.29	+0.38

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft)

radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn. The maximum excursion out of lane was 0.80 m (3.62 ft). It was out of the exit lane for a distance of 8.40 m (27.56 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was 1.66 m (5.45 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle easily made it through the channel, with the left front wheel tracking right on the outer curb.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. The dolly was not equipped with a booster relay valve to speed the signal. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi). Pressure transducers were installed at all trailer and dolly axles.

The SAE J982a style test was performed for the full double combination. The results of this test, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application times

of this test were typical of those obtained from tests conducted on other double combinations [14]. The release times are considered long. A typical time history response of application and release for the full double combination is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.03	0.18	98.3
Axle 2	0.43	0.64	97.5
Axle 4	0.54	1.65	93.3
Axle 5	0.53	1.59	95.5
Axle 6	0.85	1.96	94.2
Axle 7	0.83	2.39	94.0
Axle 8	0.83	2.43	94.2

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The brake application of about 310 kPa (45 psi) caused all braked wheels to lock. The tractor was jackknifing to the left when the driver momentarily released the brakes and steered to the right. The second trailer swung to the left but then straightened up as the vehicle came to a stop. The driver managed to arrest the jackknife, but would not have been able to at the higher speed. If the tractor

front axle brakes had been used, it is probable the tractor would not have jackknifed at this speed.

A summary of peak vehicle responses from the runs is shown in Figure 12, as a function of average treadle valve pressure. The limit of surface adhesion of about 0.15 g was reached at a brake pressure of about 173 kPa (25 psi), and the tractor started to jackknife at a brake pressure of about 290 kPa (42 psi).

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration for all three vehicle units tended to increase with speed. The vehicle maintained stability up to approximately 63 km/h, at which point the tractor was unable to maintain, consistently, a trajectory through the course. No higher speed was attempted. Tractor steer input remained relatively uniform throughout the speeds tested, indicating some sliding but no serious instability. The driver noted slight "push" of the tractor and tire "howl." There was insufficient sideforce on the low-friction surface to cause any B-dolly steer. From that point of view, therefore, this vehicle was behaving as a B-train in this manoeuvre. A typical run at 63 km/h is shown in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 84 and

94 km/h, with steer input periods between about 2 and 5 s. Weather conditions precluded runs at 63 km/h.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration for the two trailers is presented in Figure 15, as a function of tractor steer input period for the two test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15 that rearward amplification increases with speed. It also increases rearward by trailer. Finally, it is also somewhat sensitive to steer period reaching the highest value of about 1.50 around 2.5 s. The results, as seen in Figure 15, show that, at highway speed, the C-train double is not a very responsive vehicle. The reason for this is that its inherent stability is rather high. Stability and response of mechanical systems have an inverse relationship. High stability means low response to input and vice versa. Figure 16 shows the response of a typical run for a steer period of about 2.5 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, which is considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with those described in the preceding sections.

The results from all runs are summarized in Figure 17. The peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all show an increase as the limiting speed of 94 km/h was reached, at which point the trailers slid to the left about 1 m into the adjacent lane. While the trailer did not roll over in this manoeuvre, it undoubtedly would have if its centre of gravity had been higher and, perhaps, at a somewhat lower speed than 95 km/h.

Lateral acceleration and roll gains are also shown in Figure 17. The lateral acceleration gains are consistent with the rearward amplification and tend to increase at a moderate rate, as does the roll gain, the largest of each being the rearmost trailer. The yaw overshoot of the trailer is also shown in Figure 17, which clearly illustrates the rear trailer swing at the limiting speed. The vehicle generally tended to slide more than roll, although substantial roll was apparent.

Figure 18 is a time history of a run at 94 km/h, the steer input, and vehicle responses. As can be seen, the vehicle was active in overshoot of both trailers with large roll angles, because of the steer action of the B-dolly.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was not very responsive, and the slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in little rear trailer sway that was perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 1.46 g/° of RMS steer input. RMS sway of the rear of the rear trailer relative to the tractor steer axle was 161 mm/° (6.35 in/°) of RMS steer input. The latter value is regarded as somewhat questionable because the articulation angles were very small.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 19. The vehicle combination was evaluated primarily in terms of the roll response of the

vehicle units. Average steady-state roll angle is presented in Figure 19 as a function of tractor lateral acceleration. At the limiting speed of 61 km/h, a lateral acceleration at 0.54 g, the steer of the B-doly caused the outrigger of both trailers to touch down, as shown in Figure 20. As Figure 19 shows, roll angles increased with speed. Average steady-state articulation angles are also shown in Figure 19. These decrease modestly with increase in lateral acceleration, and as a consequence, the off-tracking decreases. Offtracking was considerably further outward for this vehicle than for the comparable A-train [3]. The lateral force experienced by the tractor fifth wheel is also shown in Figure 19, as a function of tractor lateral acceleration. This shows a gradient of 8.9 kN/g (2000 lb/g).

A tilt test was conducted on this vehicle as part of a separte test program [15]. The vehicle is shown on the tilt table in Figure 21. The high-side wheels of the vehicle lifted at a tilt angle of 28.0°, after all corrections were made, which corresponds to a lateral acceleration of 0.53 g. This is in quite a good agreement with the lateral acceleration at outrigger touchdown of 0.54 g. A full discussion of the tilt test is presented elsewhere [15].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, in both empty and loaded conditions. In both conditions, the centre of gravity was somewhat lower than normal, because of the underslung outriggers.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. The short trailer wheelbase made it easy to manoeuvre in both low-speed turns, though high driver effort was required in these and dynamic tests, as the trailer imposed rather significant forces on the tractor. The driver could feel the trailers pushing the tractor through a manoeuvre once it had started, because the B-dolly did not steer initially, if at all, on the low-friction surface. The vehicle was somewhat less responsive -- more stable -- than the comparable A-train [3]. The driver felt it handled quite well when returning to Centrailia from Blainville in snow and icy road conditions.

6/ CONCLUSIONS

A C-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The short trailers and articulation points of this vehicle clearly contributed to the modest space required to make turns.

The air brake system was typical of doubles without a booster relay valve

The lateral/directional stability of the vehicle was moderate, both empty on a low-friction surface and loaded on a high-friction surface. The roll stability was high, primarily because of the low trailer centre of gravity height. A higher centre of gravity would significantly reduce the roll threshold.

The C-train double configuration is preferable to the A-train double configuration because of its higher stability at highway speeds, as demonstrated in a parallel series of tests.

7/ REFERENCES

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[3] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-03, June 1986.

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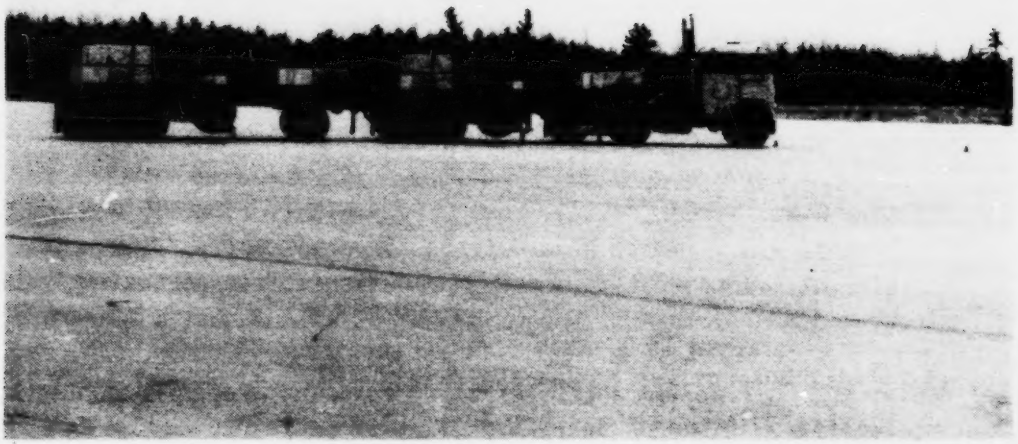


Figure 1/ C-Train Double, View of Vehicle

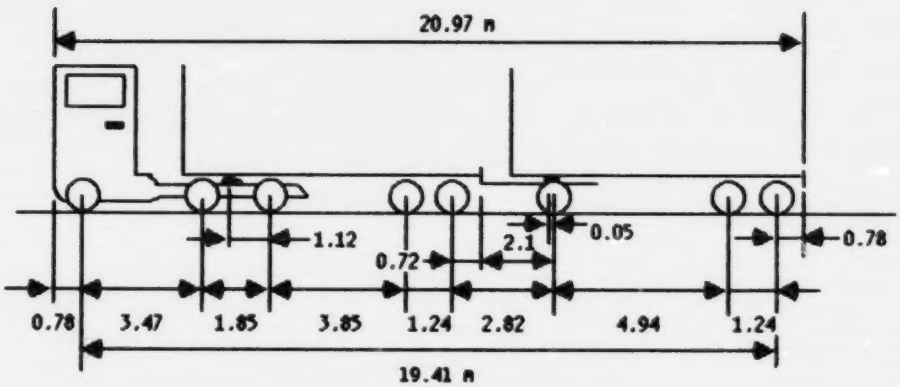


Figure 2/ C-Train Double, Vehicle Dimensions

Figure 3/ C-Train Double,
Clockwise Offtracking

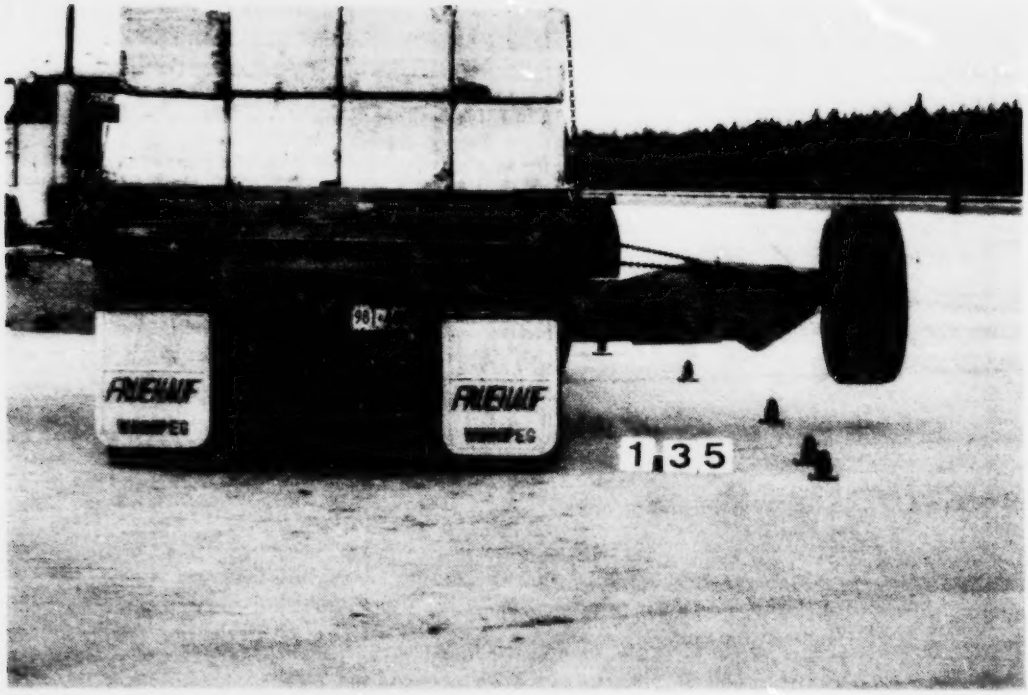
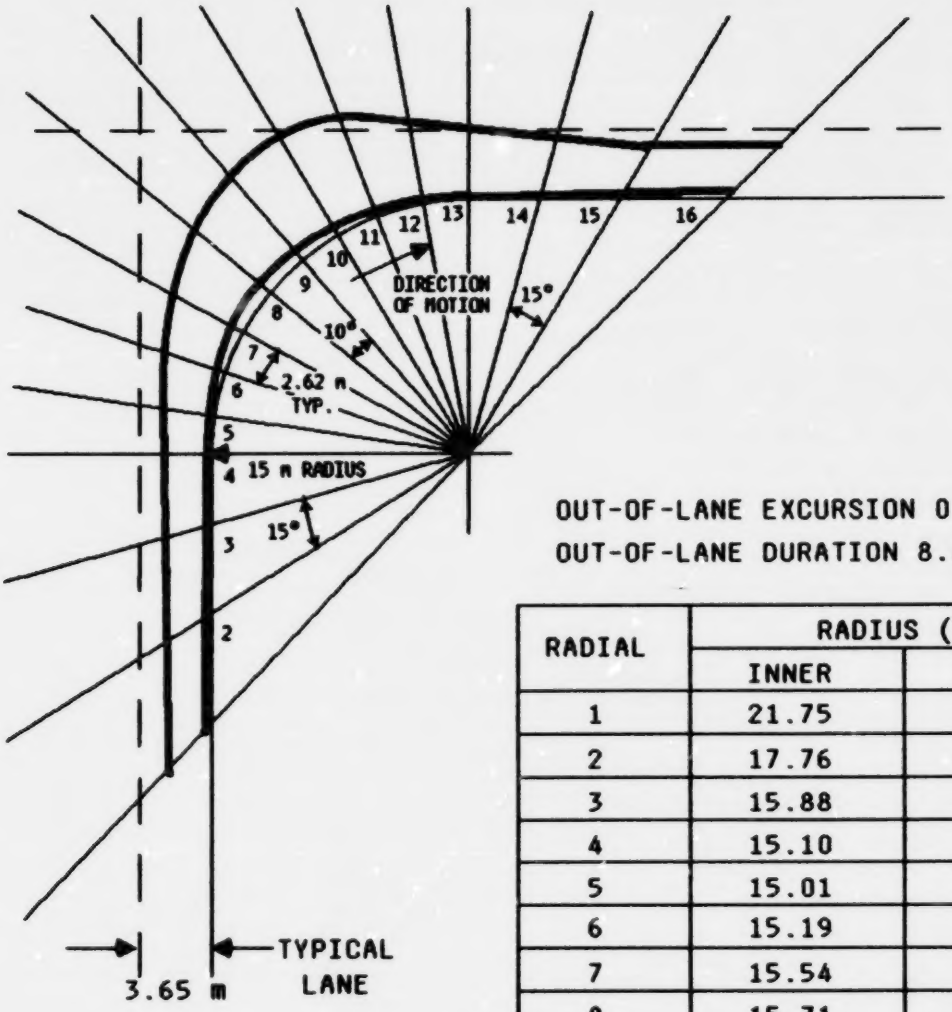


Figure 4/ C-Train Double,
Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 0.8 m

OUT-OF-LANE DURATION 8.4 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	21.75	25.10
2	17.76	20.16
3	15.88	18.21
4	15.10	17.54
5	15.01	17.81
6	15.19	18.58
7	15.54	19.23
8	15.71	20.19
9	15.66	21.17
10	15.34	21.43
11	15.05	20.99
12	15.00	19.45
13	15.00	18.47
14	15.66	18.73
15	17.59	20.05
16	21.50	24.80

Figure 5/ C-Train Double, Right-Hand Turn Swept Path

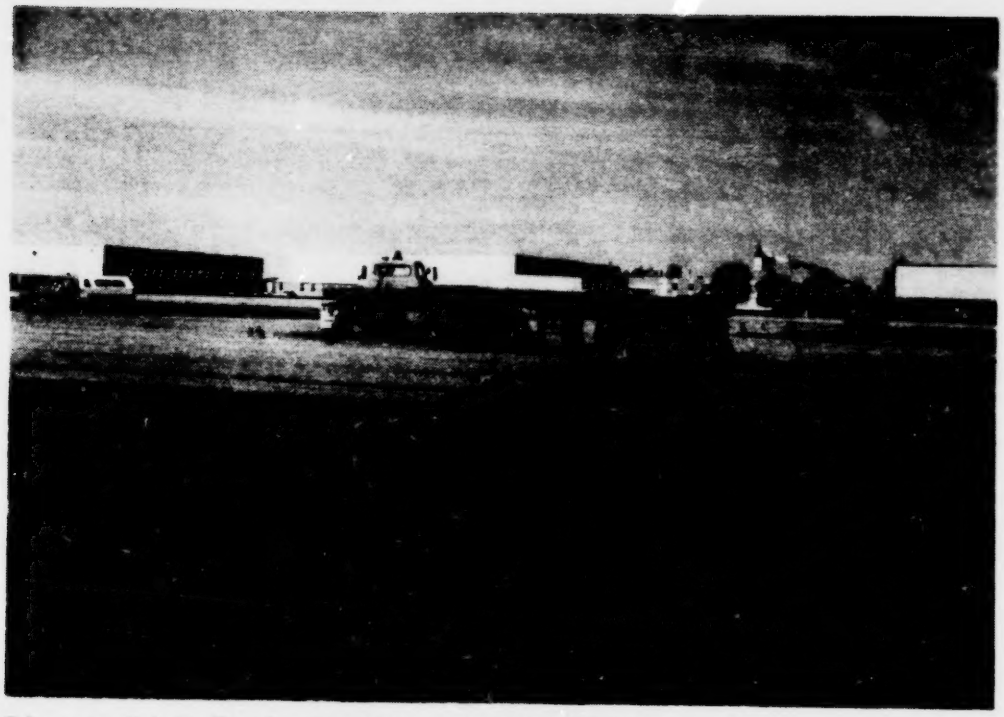
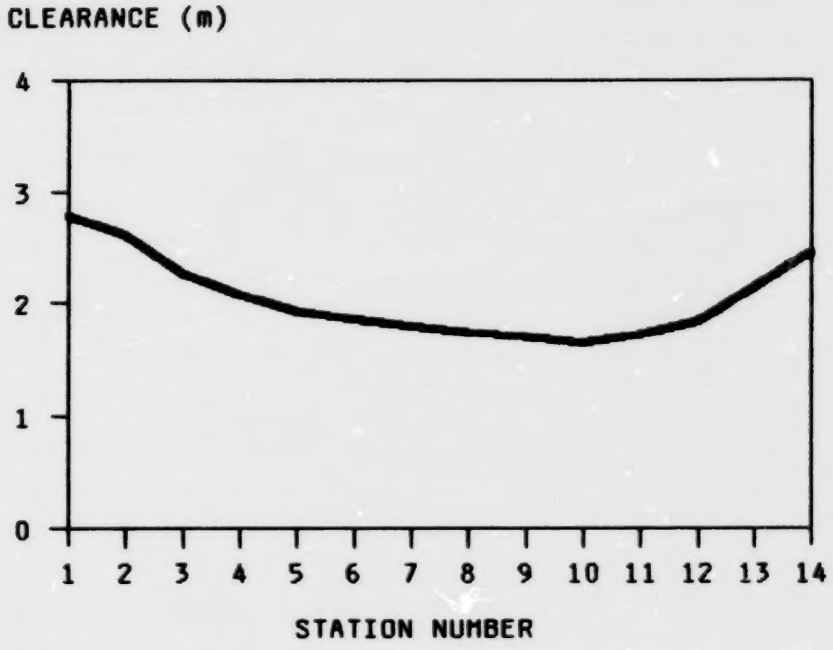


Figure 6/ C-Train Double, Right-Hand Turn

Figure 7/ C-Train Double, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.78
2	2.62
3	2.26
4	2.08
5	1.94
6	1.86
7	1.79
8	1.75
9	1.69
10	1.66 *(LOW)
11	1.71
12	1.85
13	2.15
14	2.45

Figure 8/ C-Train Double, Channelized Right-Turn Clearance from Inner Curb

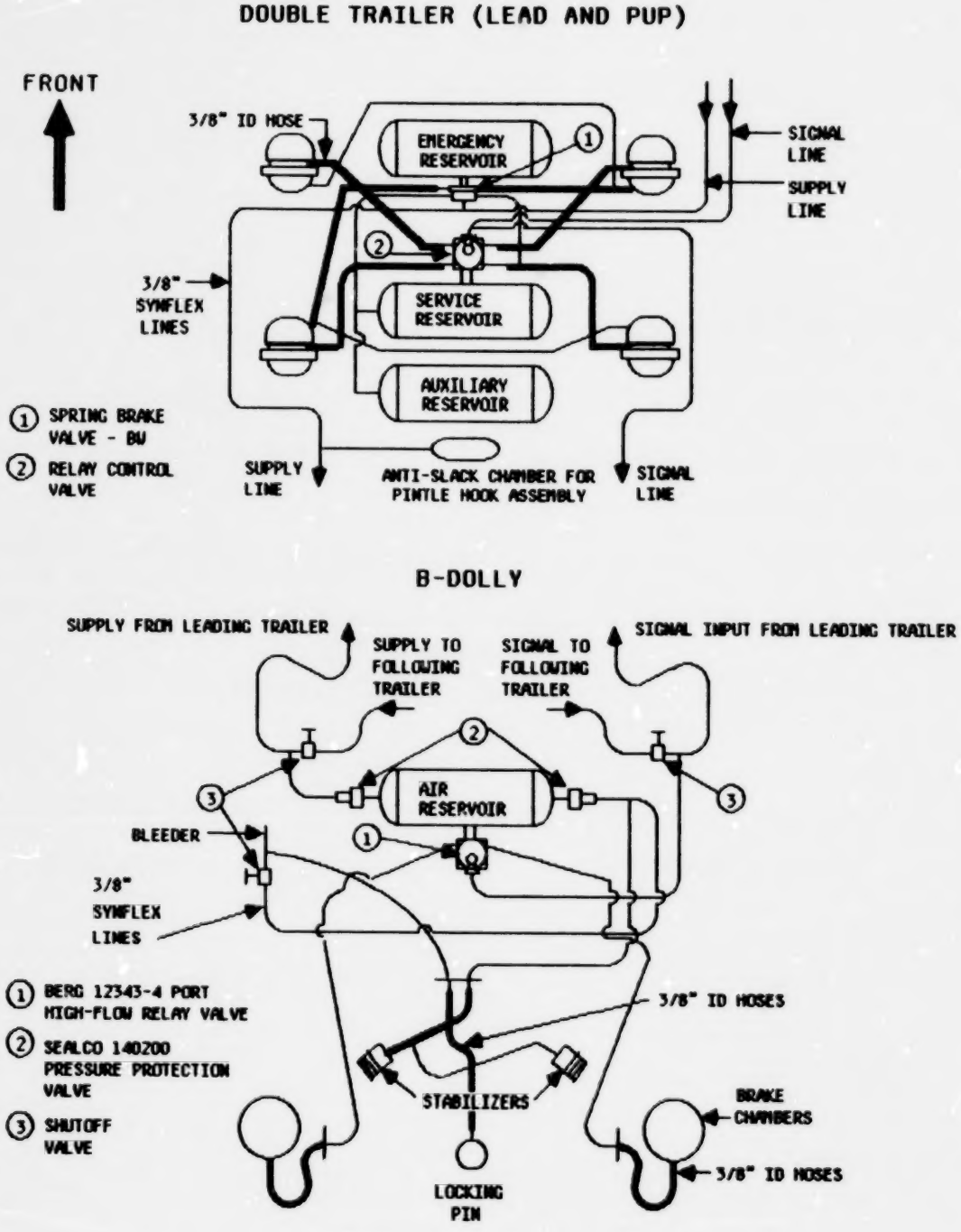


Figure 9/ C-Train Double Trailers and Dolly, Air Brake System Schematic

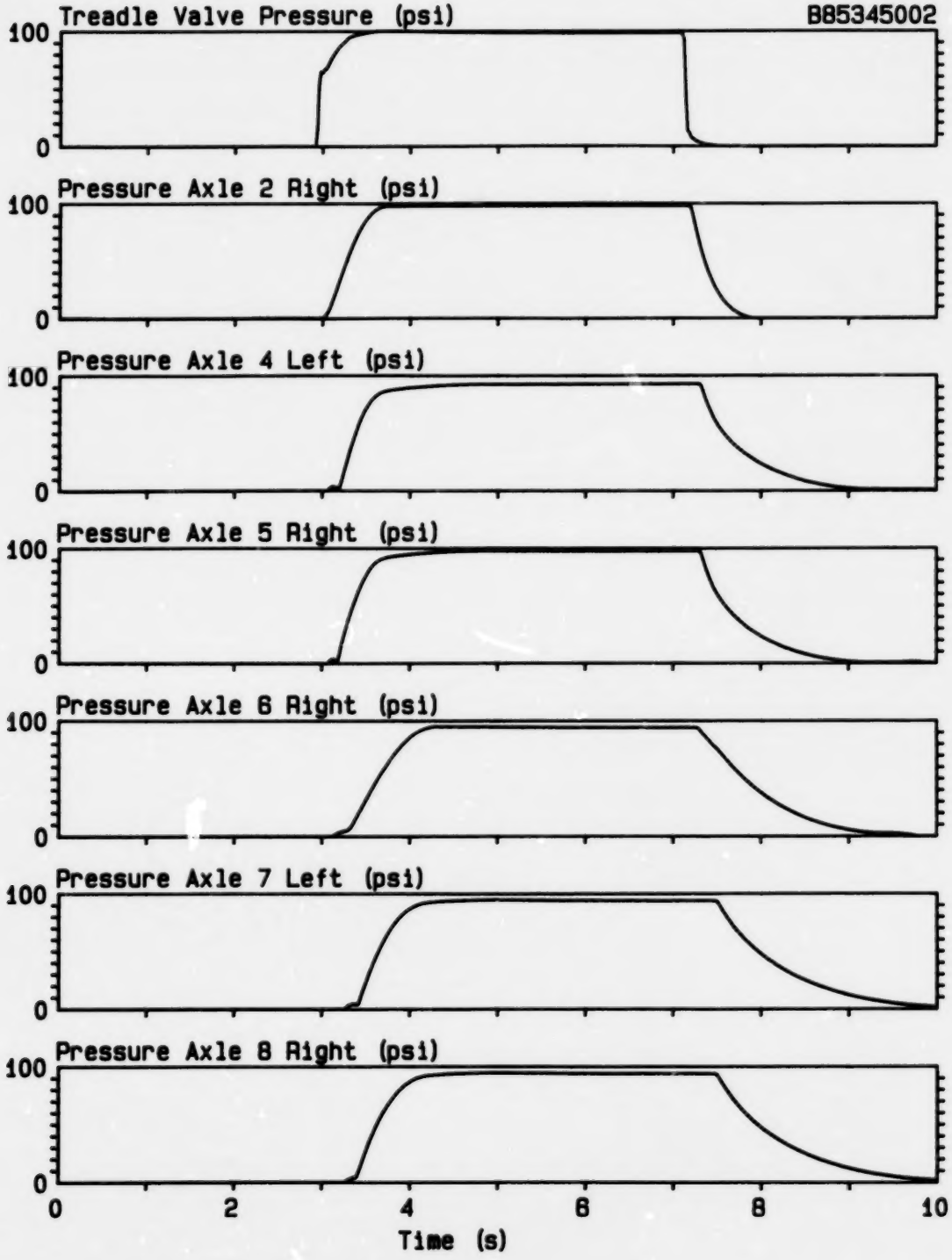


Figure 10/ C-Train Double,

Air Brake Application and Release

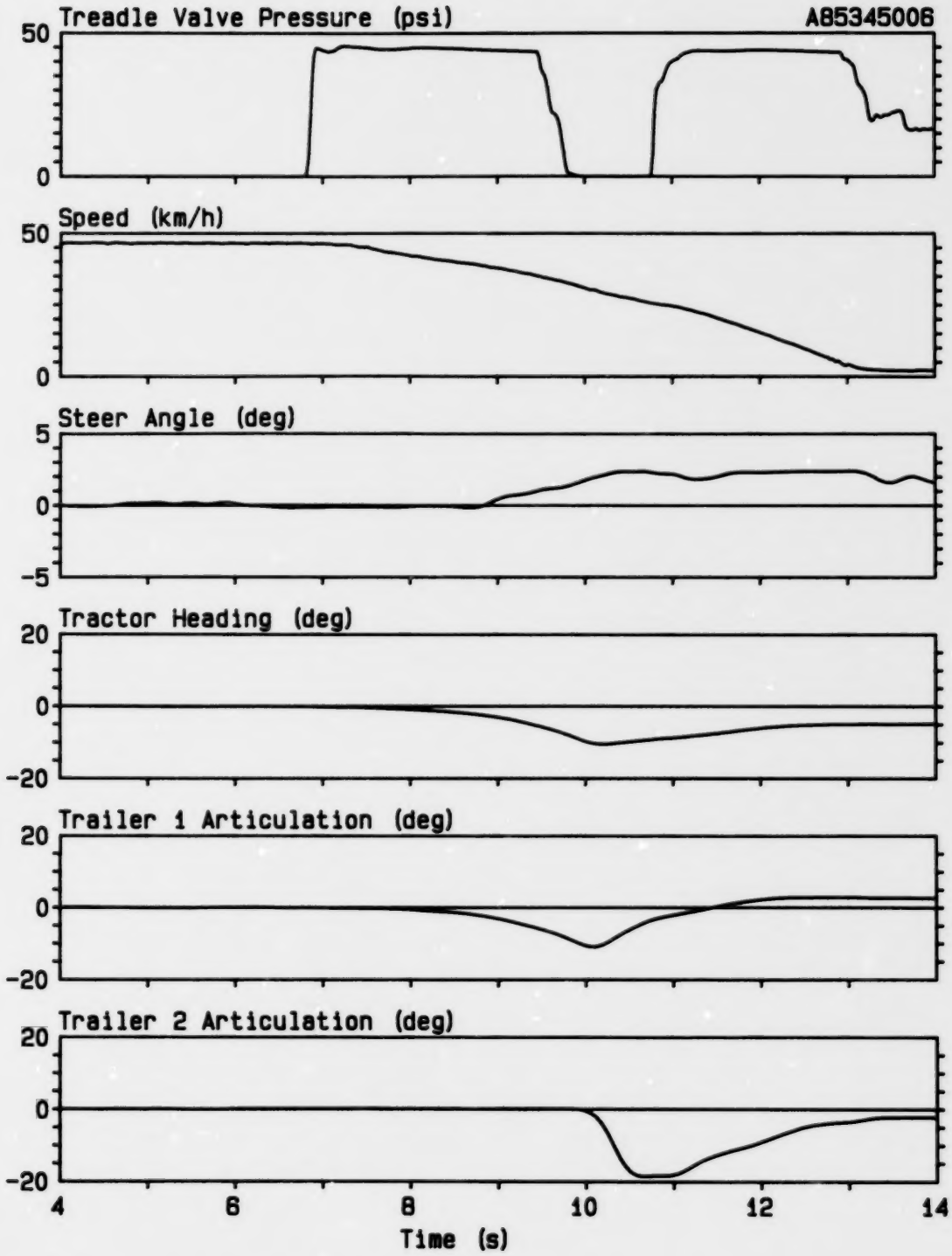


Figure 11/ C-Train Double,

Vehicle Response to Straight-Line Braking

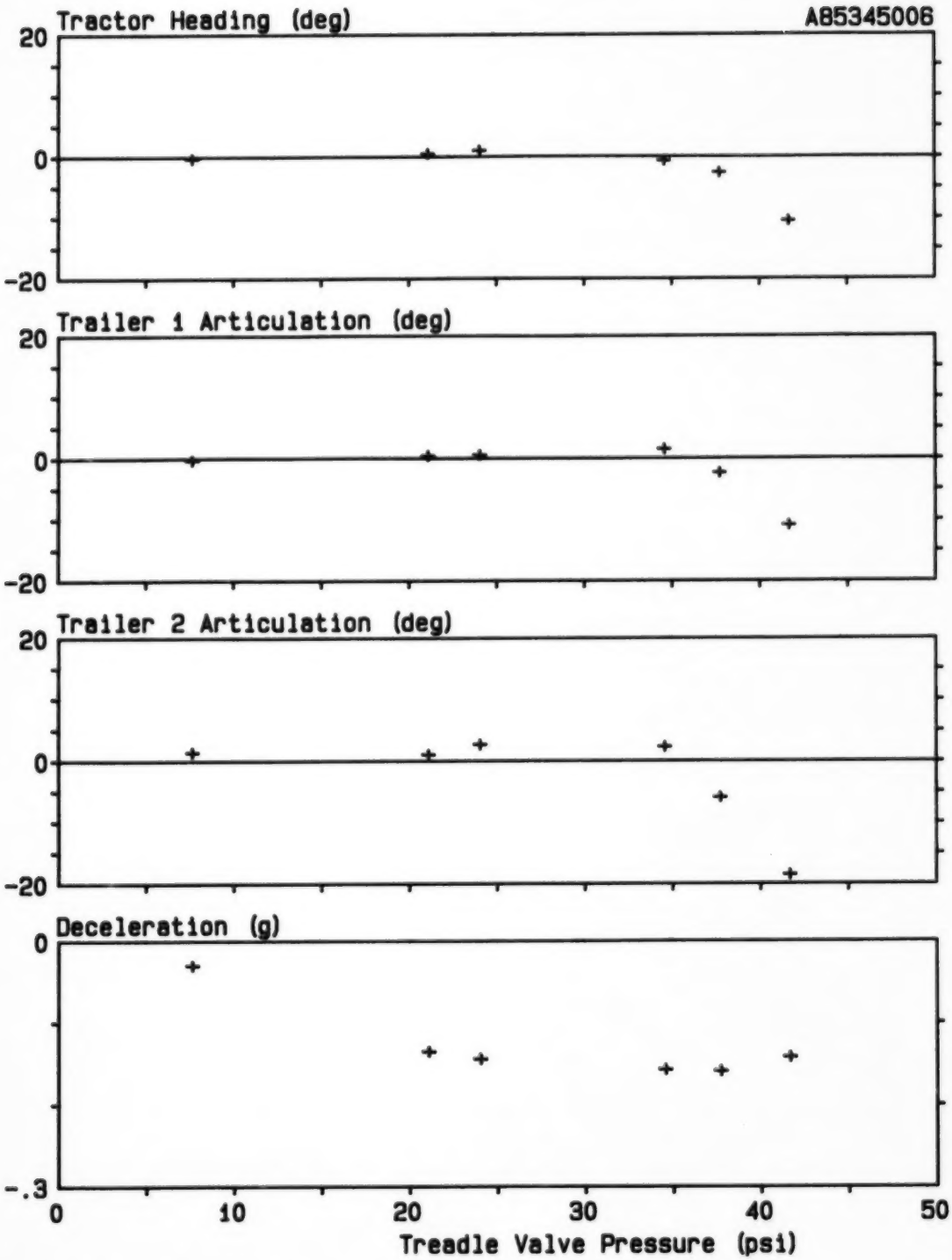


Figure 12/ C-Train Double, Straight-Line Braking Responses vs Treadle Valve Pressure

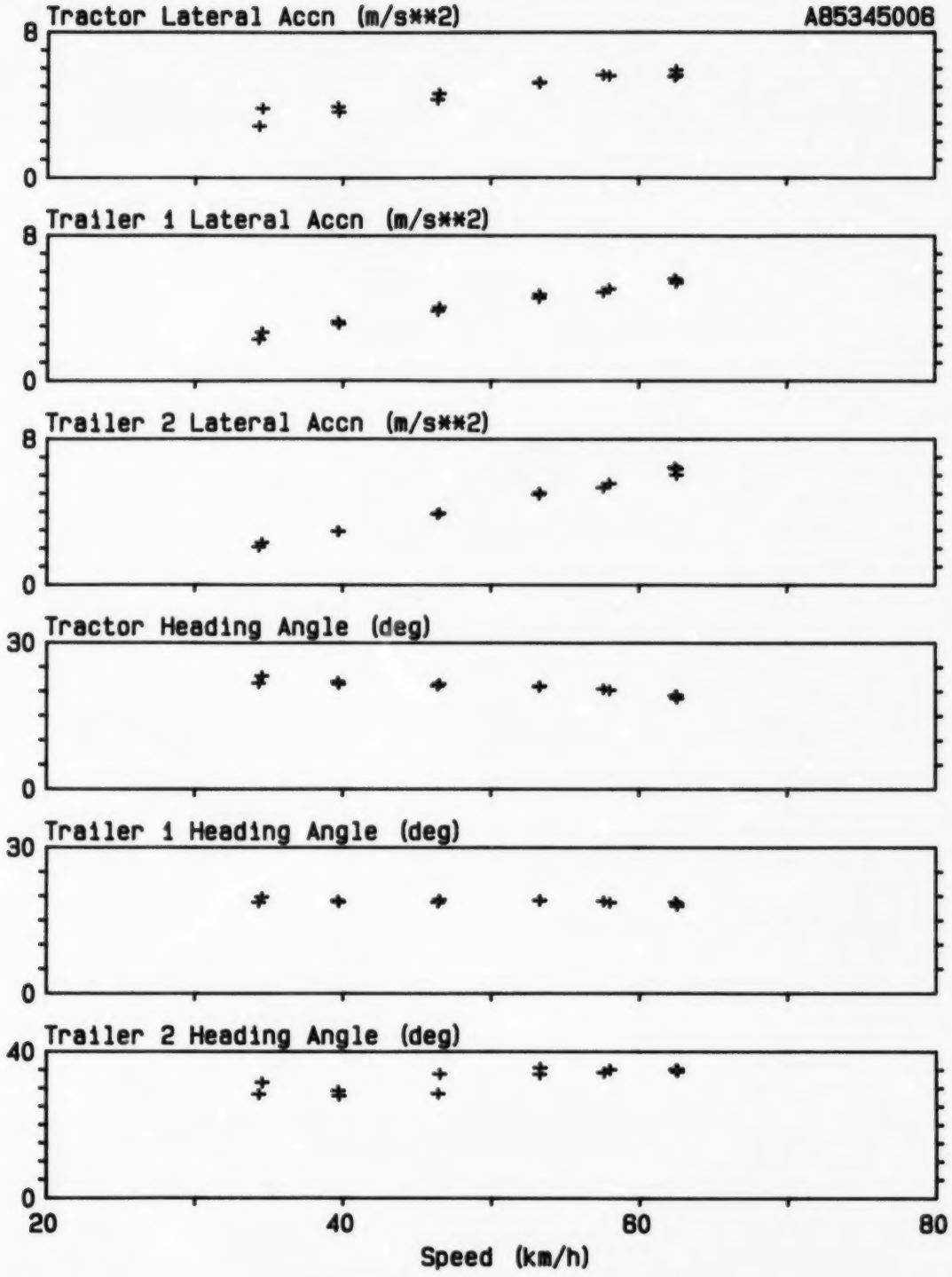


Figure 13/ C-Train Double, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed

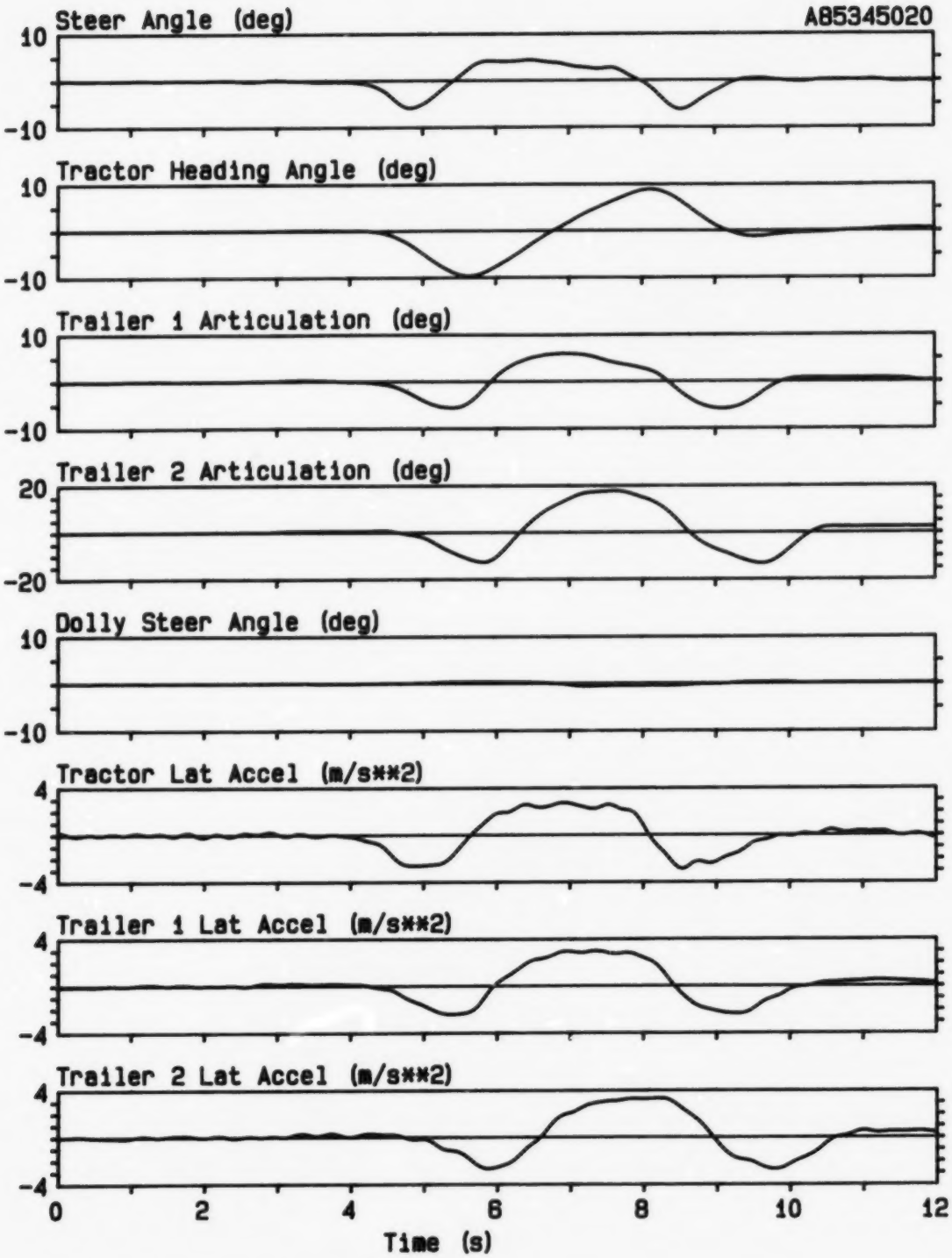


Figure 14/ C-Train Double,

Vehicle Response in Evasive Manoeuvre

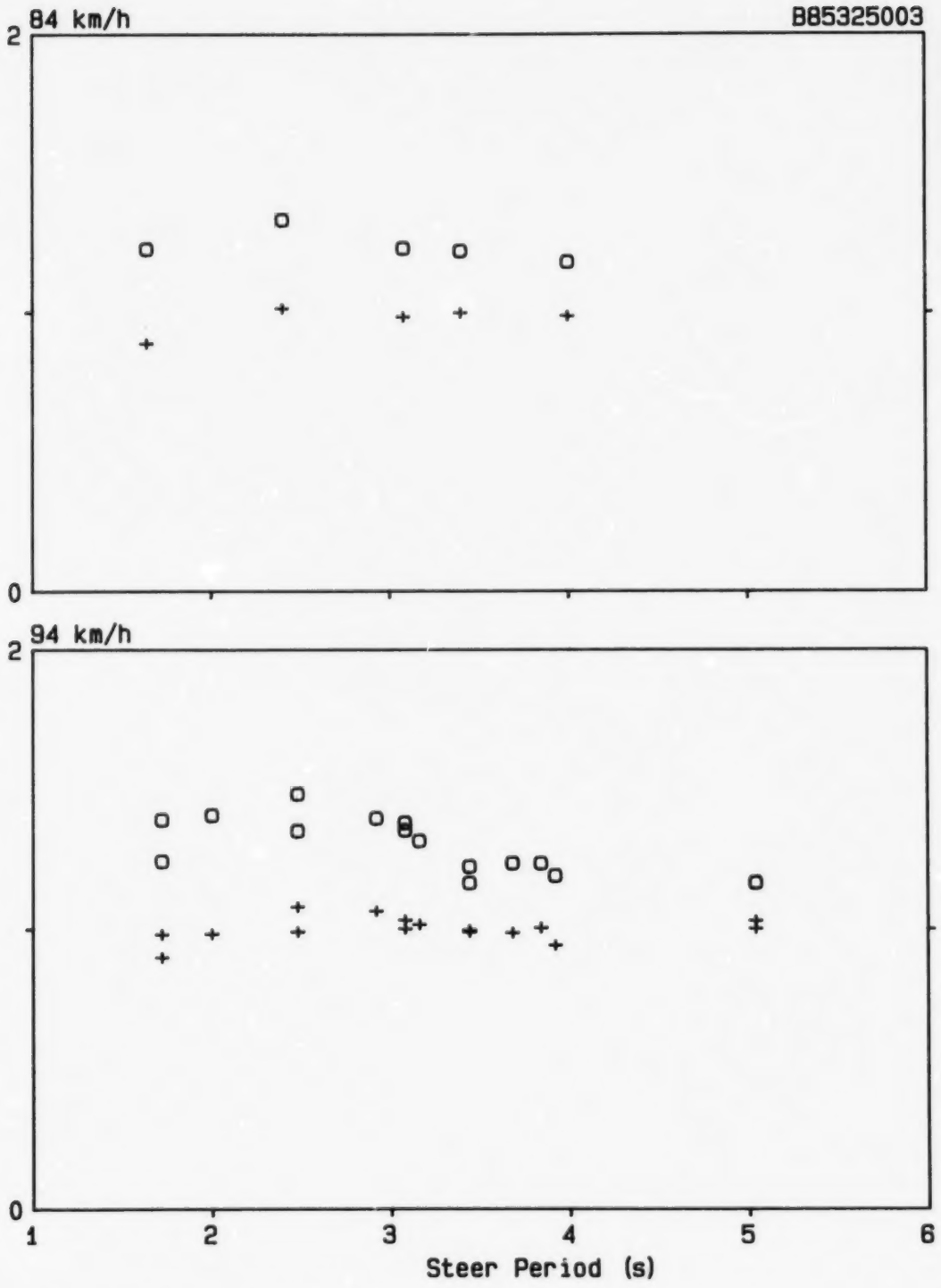


Figure 15/ C-Train Double,

Rearward Amplification of Lateral Acceleration

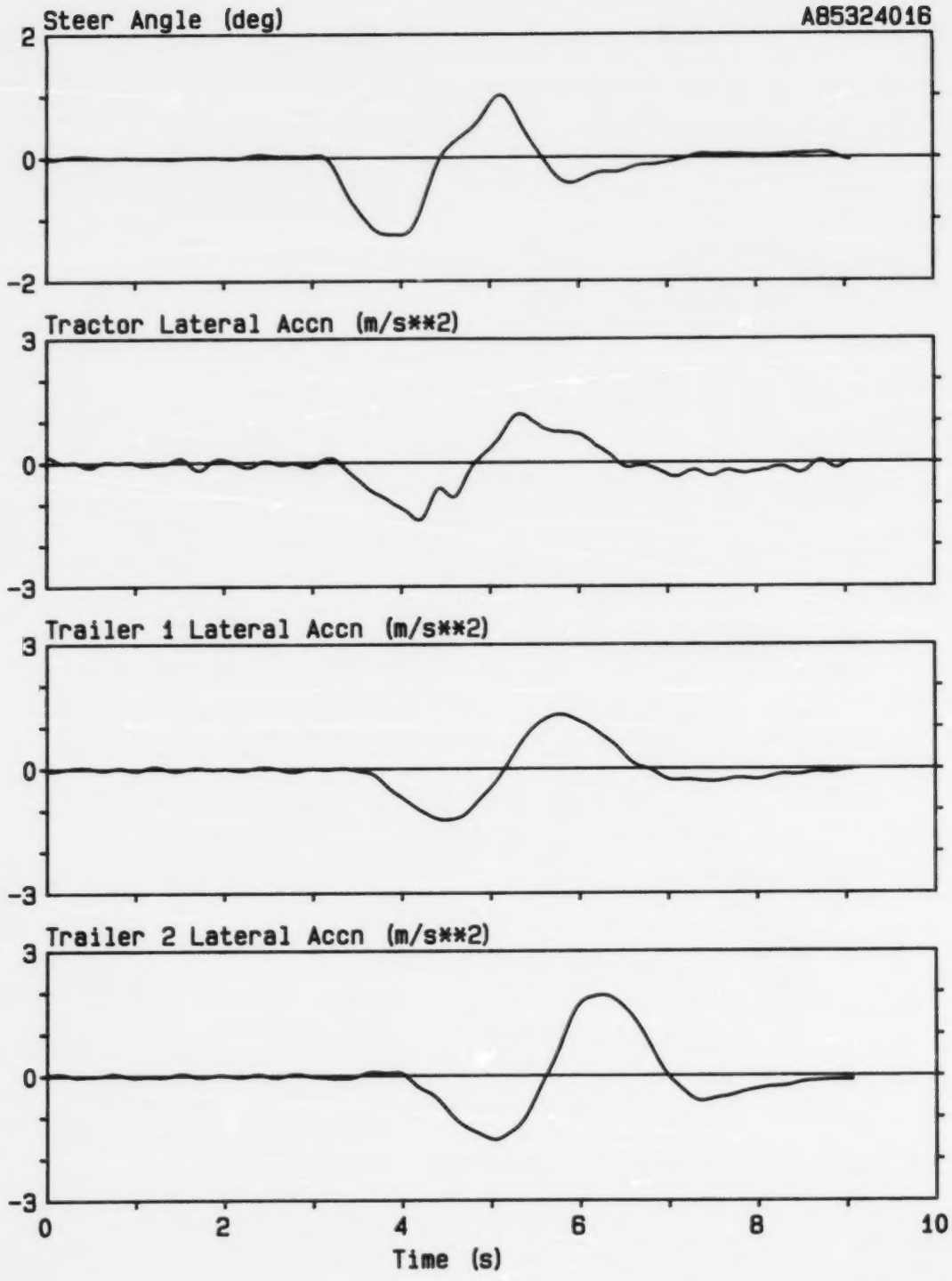


Figure 16/ C-Train Double, Sinusoidal Steer,

Vehicle Responses at 94 km/h

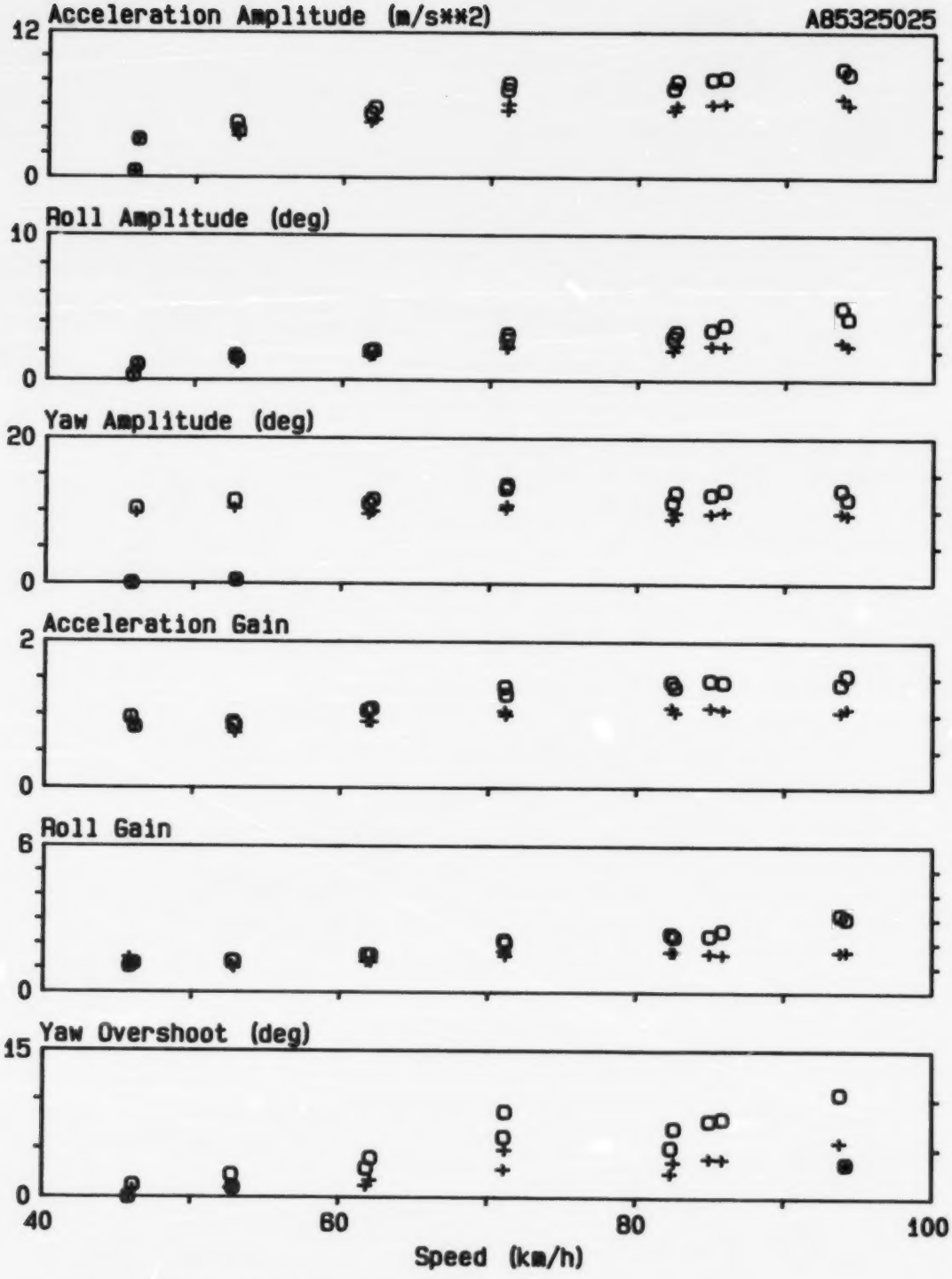


Figure 17/ C-Train Double, Lane Change,
Vehicle Responses vs Speed

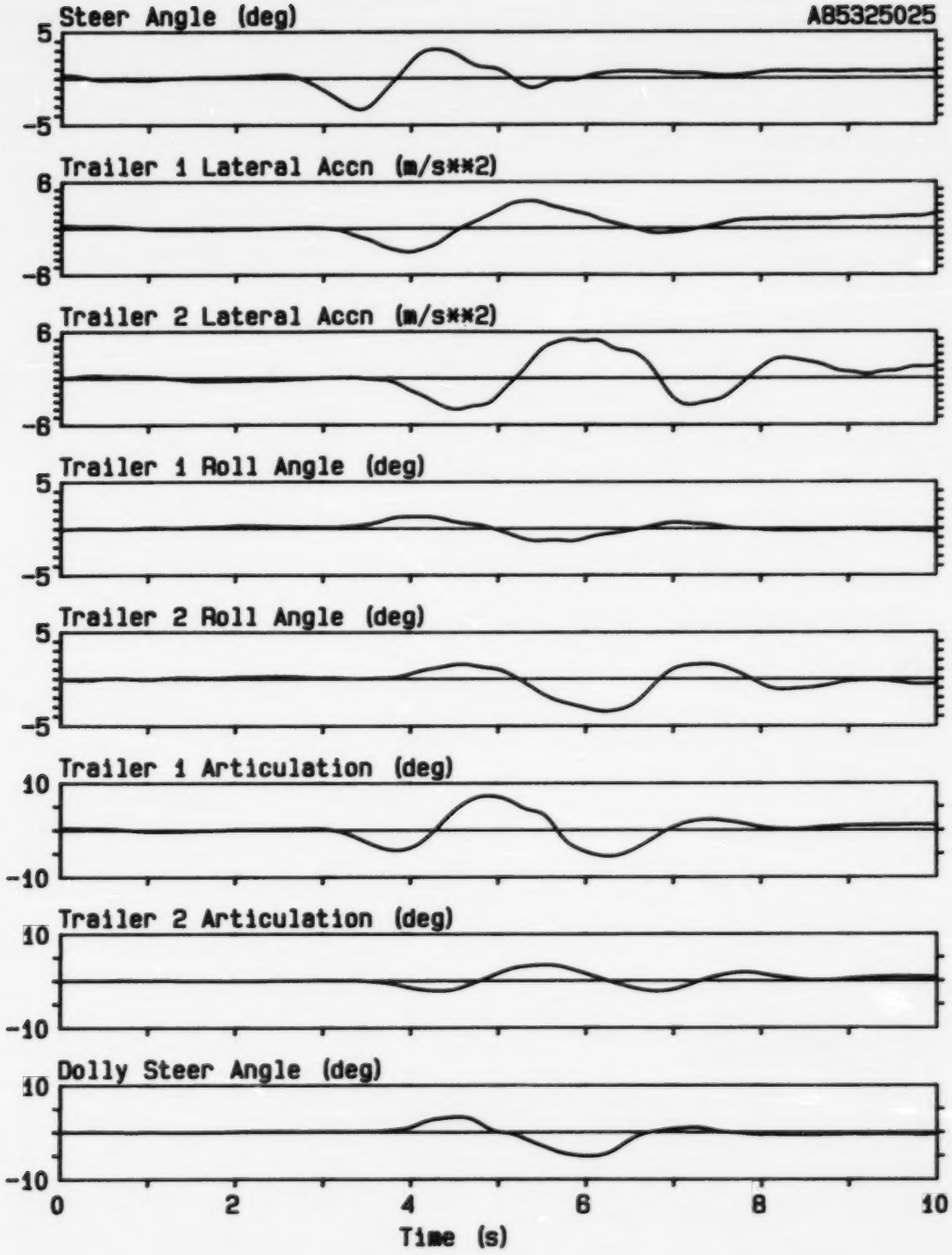


Figure 18/ C-Train Double, Lane Change,

Vehicle Responses at 95 km/h

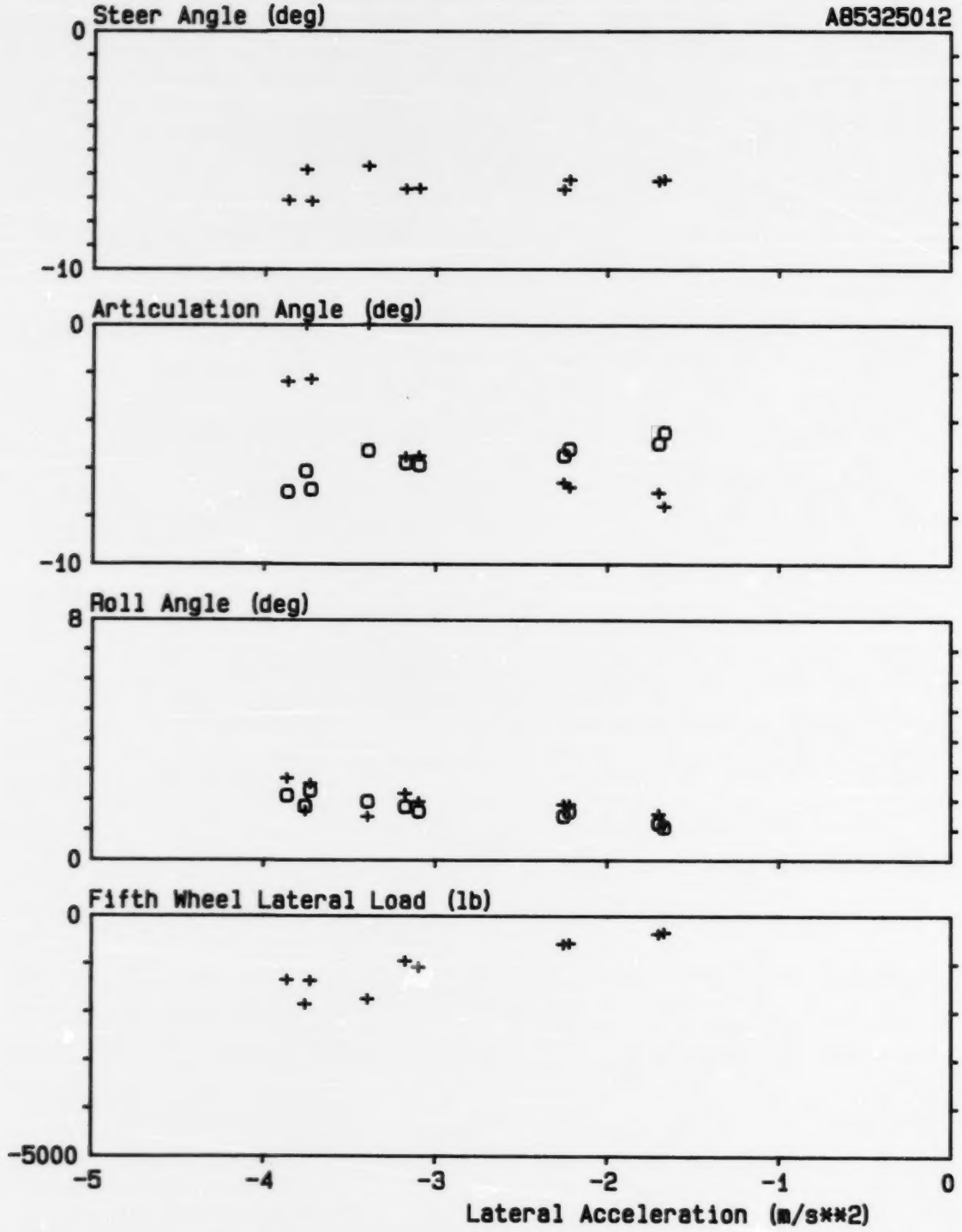


Figure 19/ C-Train Double, Steady Circular Turn,
Vehicle Responses vs Tractor Lateral Acceleration

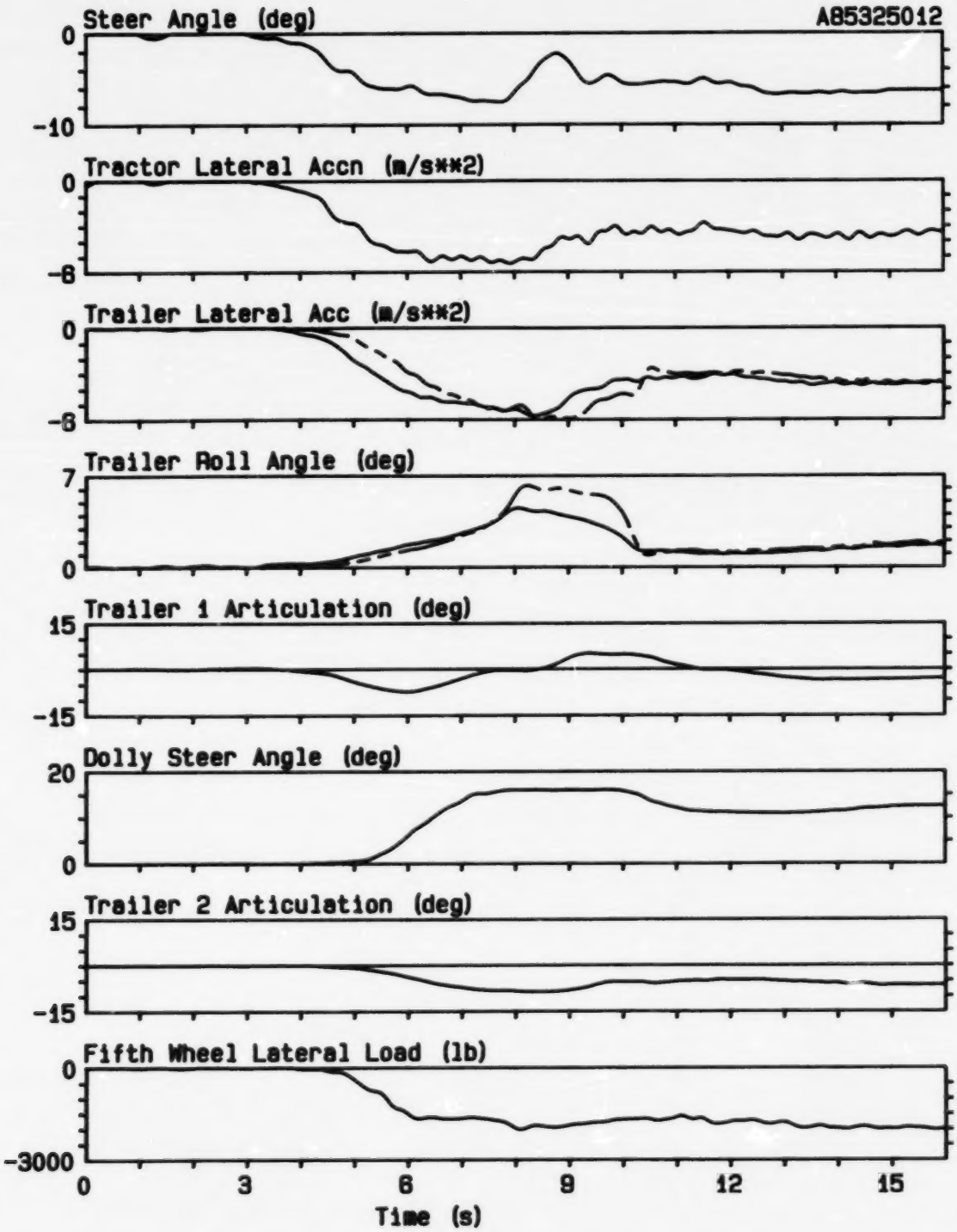


Figure 20/ C-Train Double, Steady Circular Turn, Vehicle Responses at 81 km/h

Figure 21/ C-Train Double on Tilt Table